Fast Cycling Superconducting Magnets

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Erice

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Outline

- The planned facility
- Superconducting magnets for the planned facility
  - fast pulsed synchrotron magnets
    - SIS 100
    - SIS 300
  - Storage rings / SuperFRS
  - other activities
- Conclusions

International Facility for Beams of Ions and Antiprotons

SIS100 (Synchrotron 100 Tm):
- „work horse"
- accelerates heavy ions/protons
- fast extraction to SIS 200 or RIB/Antiproton targets

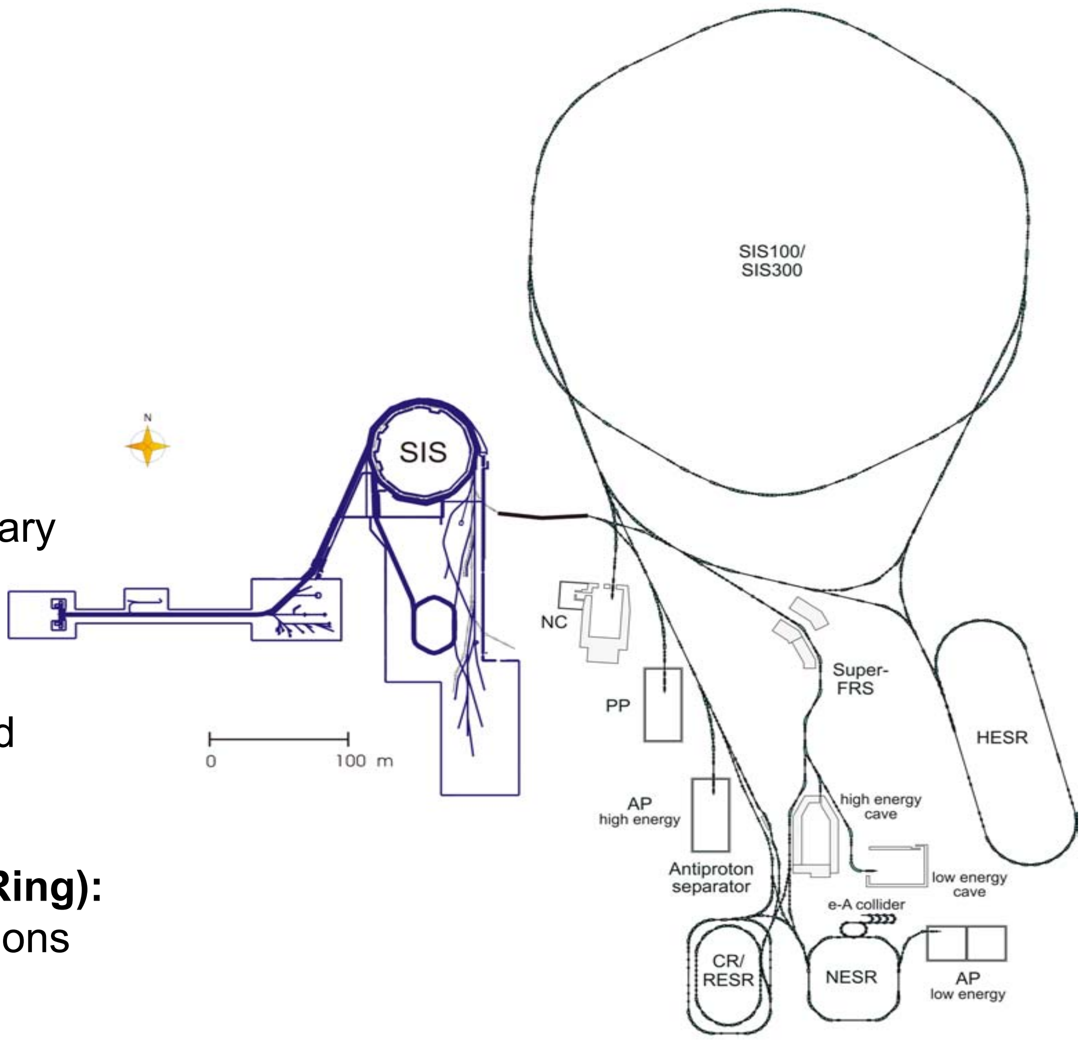
SIS300 (Synchrotron 300 Tm):
- stretcher ring
- accelerates heavy ions to high energies
- slow extraction

SuperFRS (Fragment Separator):
- analyses and separates secondary beams

CR (Collector Ring complex):
- collects secondary beams
- stochastic precooling of ions and antiprotons
- storage of antiprotons

NESR (New Experimental Storage Ring):
- electron cooling and storage of ions
- in-beam experiments with RIB

HESR (High Energy Storage Ring):
- experiments with antiprotons



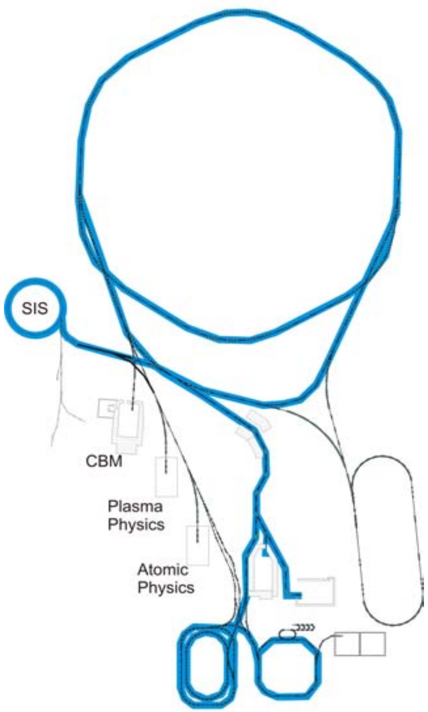
Key Parameters: Synchrotrons

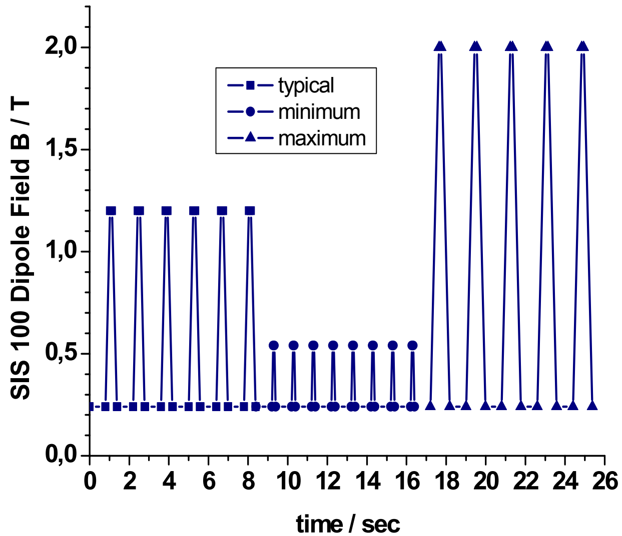
Ring	Circum ference	Bending Power	Reference Energy	Special Features
SIS 100	1080 m	100 Tm	2.7 GeV/u U^{28+} 29 GeV protons	• fast pulsed superferric magnets (2 T and 4 T/s)
SIS 300	1080 m	300 Tm	34 GeV/u U^{92+}	• fast pulsed superconducting $\cos\theta$ magnets (6 T and 1 T/s)

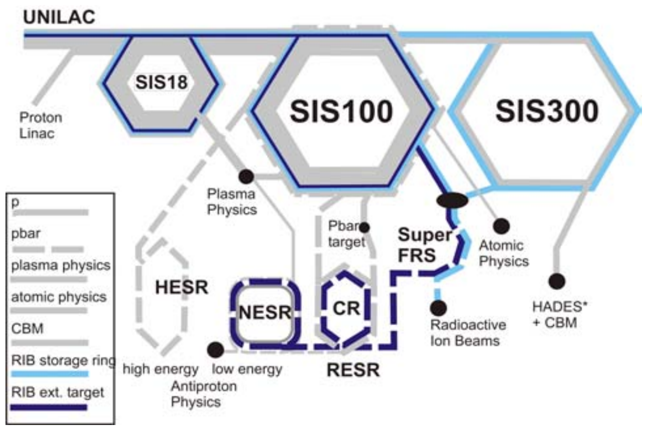
Key Parameters: Storage Rings

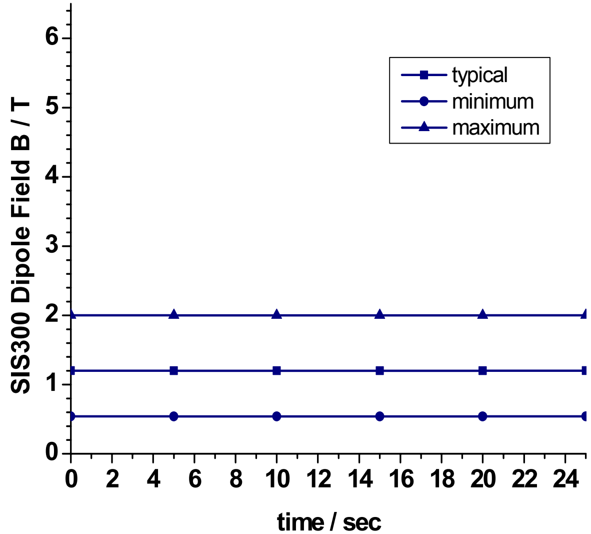
Ring	**Circum ference**	Bending Power	Reference Energy	Special Features
CR	187 m	13 Tm	740 MeV/u with A/q=2.7 3 GeV antiprotons	• large aperture superferric dipoles
NESR	208 m	13 Tm	740 MeV/u with A/q=2.7 3 GeV antiprotons	• large aperture superferric dipoles
HESR	430 m	50 Tm	14 GeV antiprotons	• 4T (curved) superconducting dipoles

Radioactive Ion Beams (RIB)









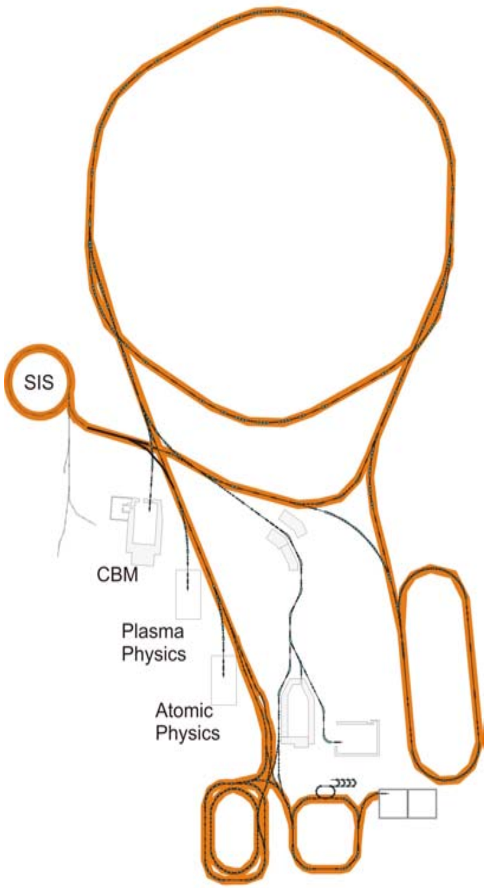
<u>For storage ring experiments:</u>

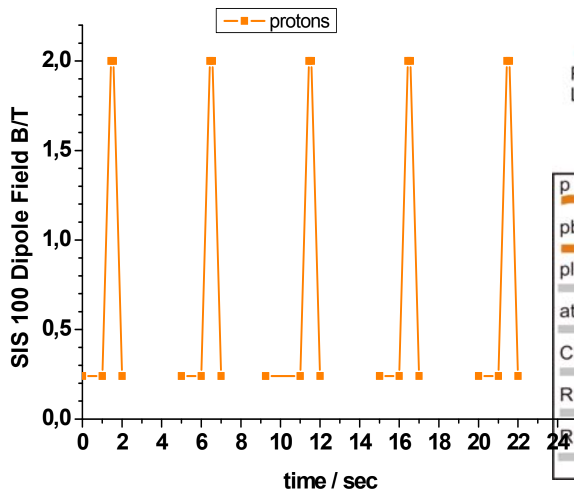
- Fast extraction SIS100

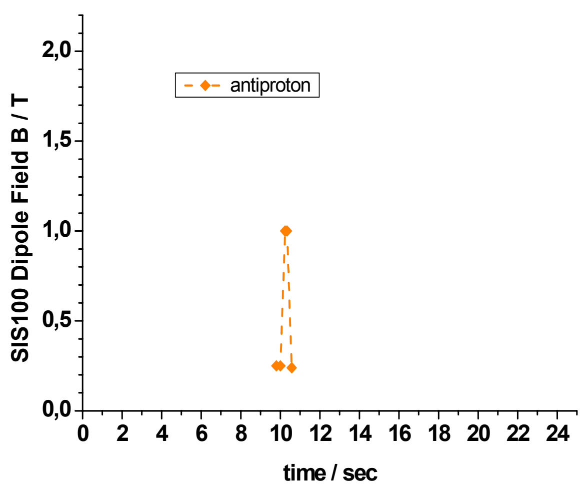
<u>For external target experiments:</u>

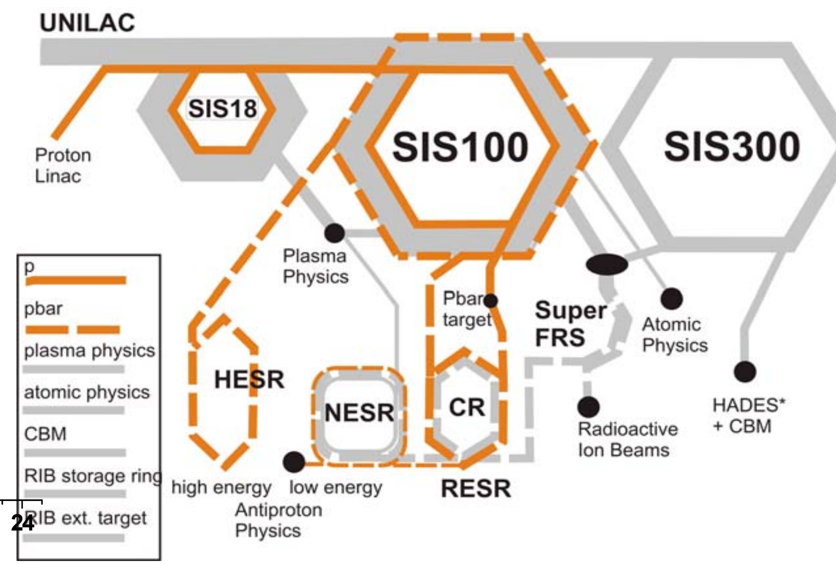
- Slow extraction from SIS300
- Slow extraction from SIS100

Antiproton Physics



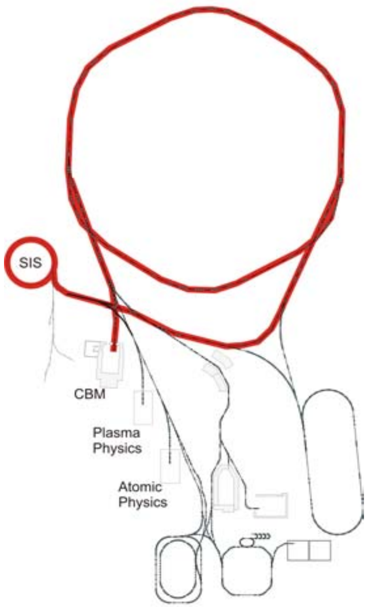


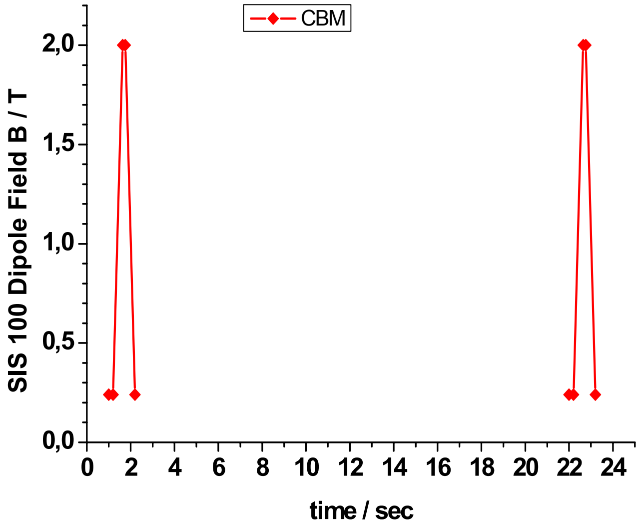


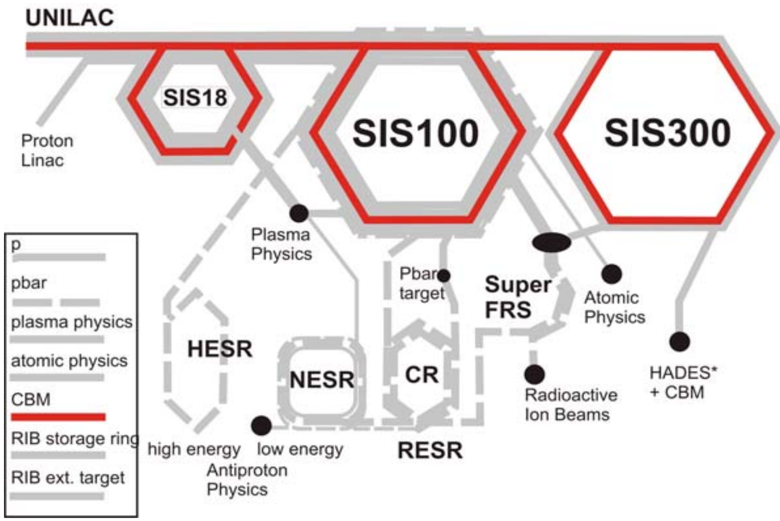


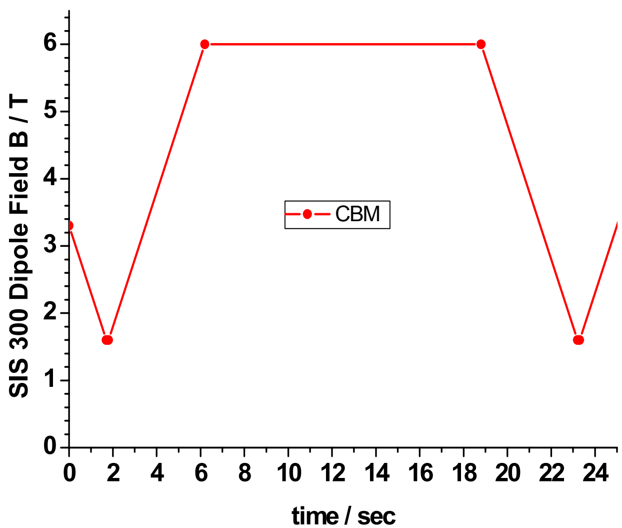
- Antiproton production
  - pauses in SIS100 for cooling in CR
- Antiproton acceleration
  - low repetition rate

Compressed Baryonic Matter (CBM)









- U^{73+} in SIS 100
- U^{92+} in SIS 300
- Slow Extraction from SIS300

R&D principles

Situation (when we started in 2000)

- small magnet group
- new field
- large variety of magnets
- tight R&D schedule and restricted budget

Consequences

- establish collaborations
- look for existing magnets with similar parameters
- start R&D for dipoles
- build model dipoles with existing material and toolings

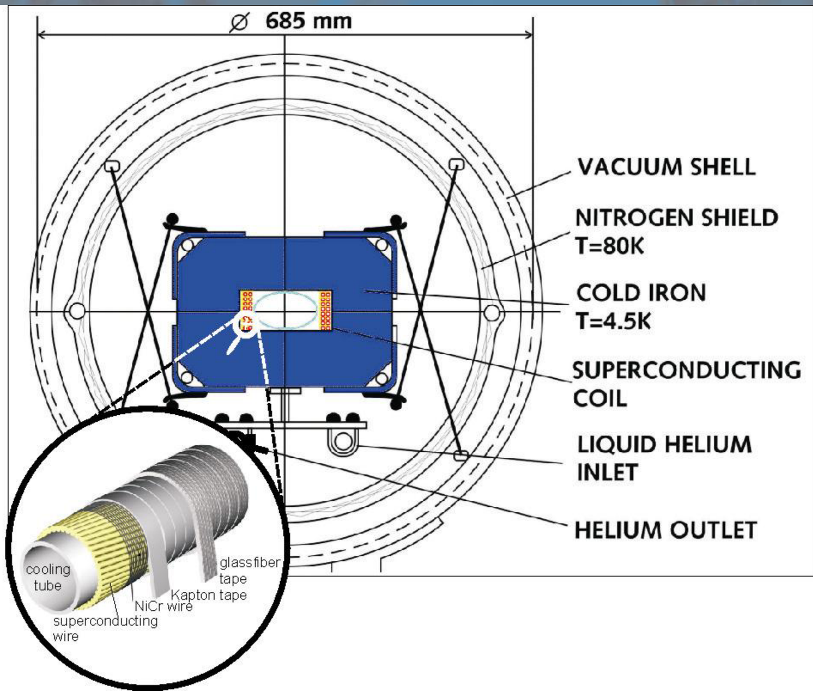
$\Rightarrow$ saves time and money

Magnets for the Synchrotrons

SIS 100	Number of Magnets	Aperture (mm)	Magnet Length (m)	Max. Field / Max.Gradient	Max. Ramprate
Dipoles	120	110 x 55	2.6	2 T	4 T/s
Quadru-poles	162	120 x 63 (pole radius: 40)	0.6 1.0 0.6	34.2 T/m 36.7 T/m 34.2 T/m	73.4 T/m/s

SIS 300	Number of Magnets	Aperture (mm)	Magnet Length (m)	Max. Field / Max.Gradient	Max. Ramprate
Dipoles	120	80 (circular)	2.6	6 T	1 T/s
Quadru-poles	132	80 (circular)	0.6 1.0	93 T/m 89 T/m	15.5 T/m/s 14.8 T/m/s

Superconducting Magnets for SIS 100

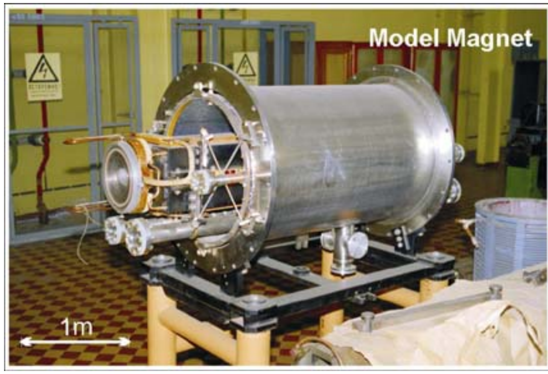


R&D goals

- **Improvement of DC-field quality**
  - 2D / 3D calculations
- **Guarantee of long term mechanical stability** ($\geq 5 \cdot 10^8$ cycles)
  - concern: coil restraint in the gap, fatigue of the conductor
- **Reduction of eddy / persistent current effects (field, losses)**

Nuclotron Dipole

- Collaboration: JINR (Dubna)
- Iron Dominated: window frame
- Maximum magnetic field: 2 T
- Ramp rate: 4 T/s
- Hollow-tube superconducting cable
- Two-phase helium cooling

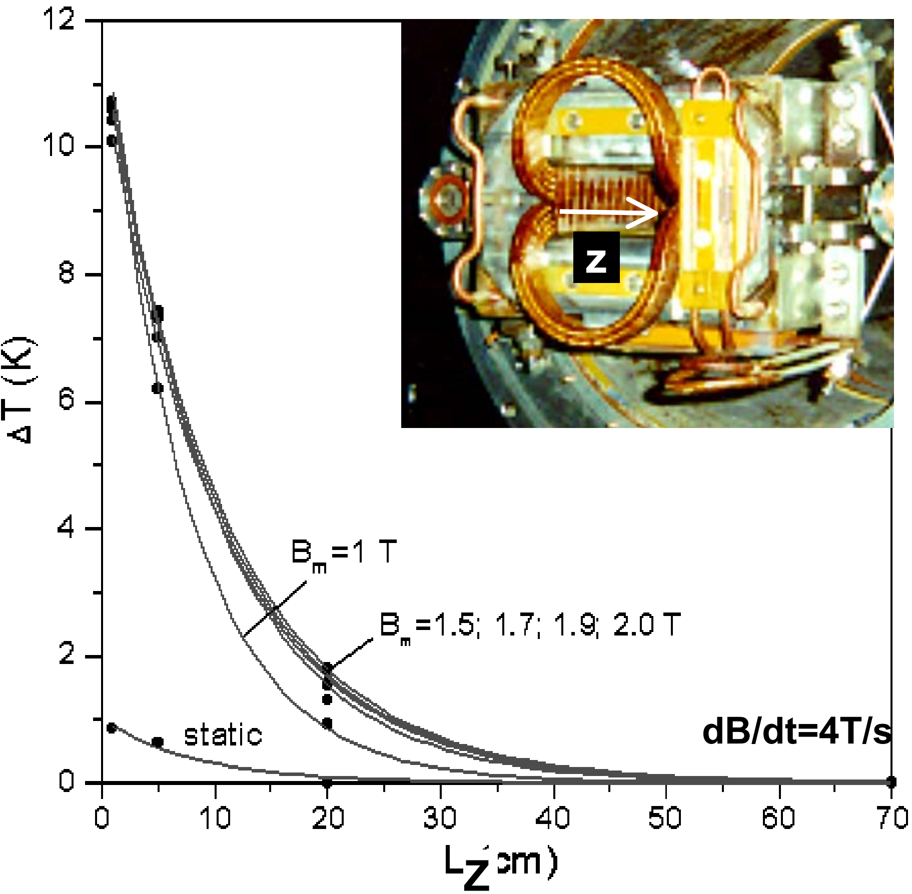


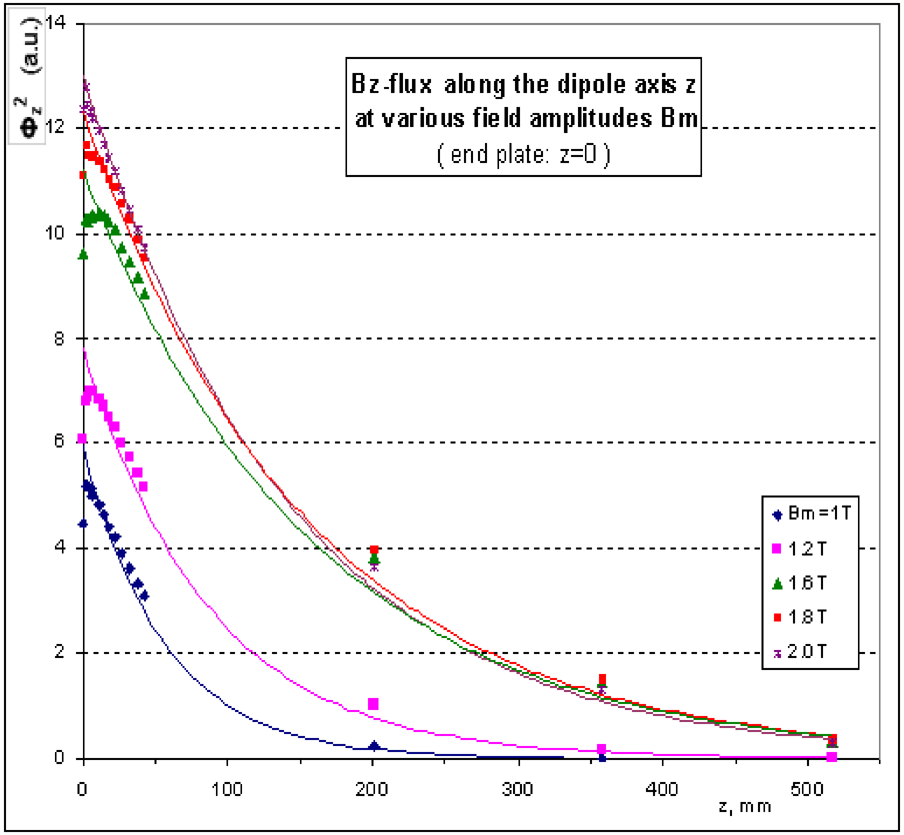
Nuclotron-type Dipole – Loss Mechanisms

Measured Heat Releases to Helium (4K) Triangular cycle: 1Hz, 0-2T	Nuclotron-Dipole (1.4 m)	80KDP2 (1.4 m) (Yoke at 80K)	planned prototype (2.6 m)
Total (W/m)	44	11	
Yoke (W/m)	> 27	0	
Coil (W/m)	12	9	
Static Heat Release (W/m)	5	2	

- **Coil (30%):**
  - main contribution: wire magnetization
    $\Rightarrow$ reduction of filament size to 3.5 mm
- **Yoke (70%):**
  - magnetization losses in the central core
  - losses in the endparts due to longitudinal field components B_z

AC Losses along Magnet axis z



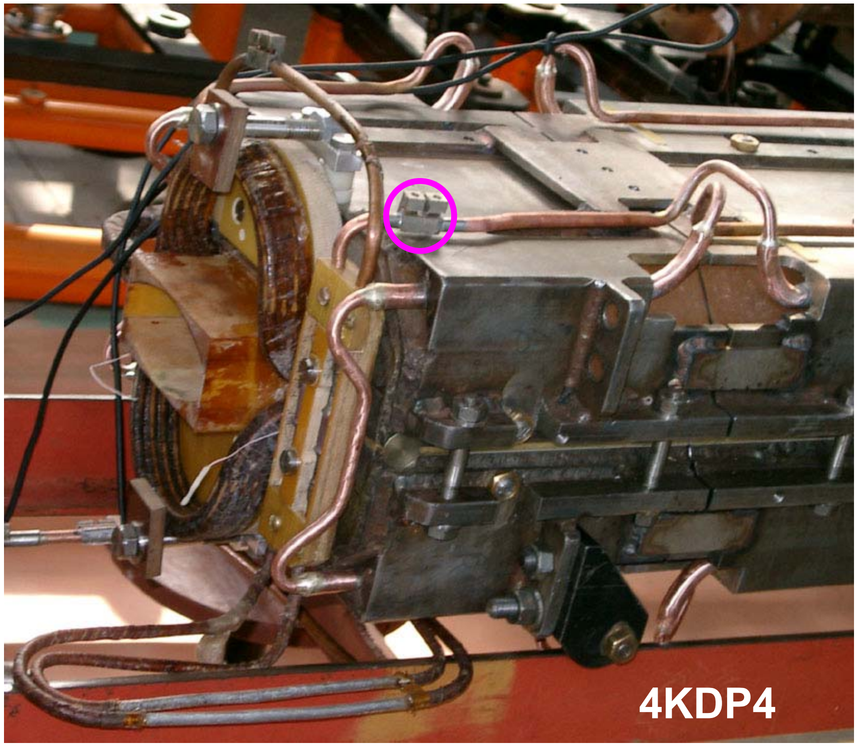


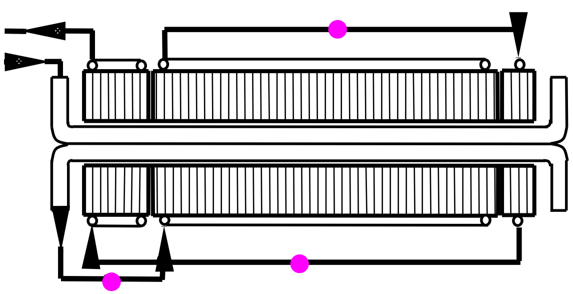
Z=0: Core edge

- Temperature rise in the end part !

- OPERA-3D calculations of the integral magnetic flux Φ (z)

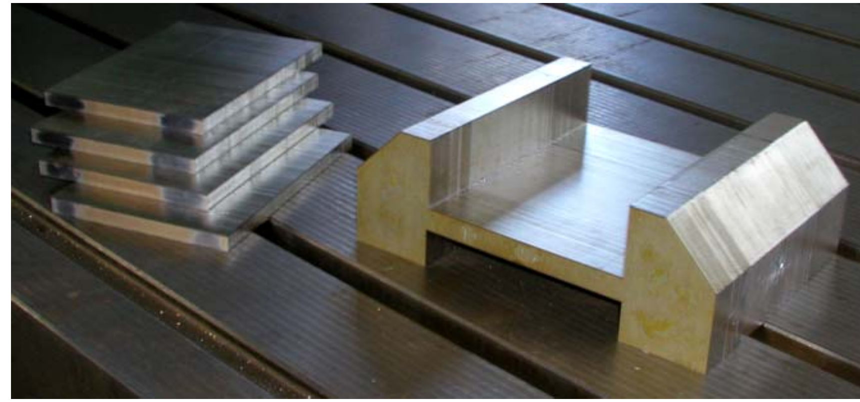
New endblocks

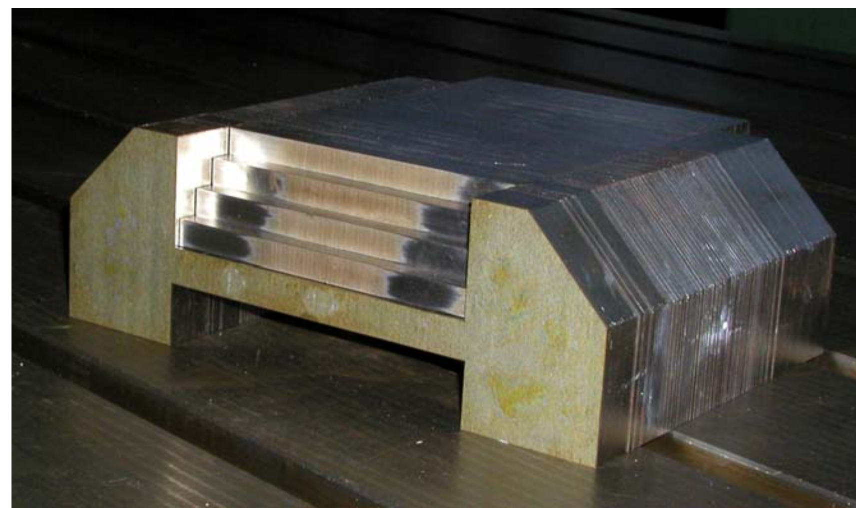




<= iron yoke partition and cooling circuit

• thermometer





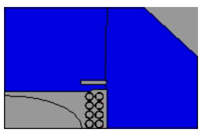
• **new 200mm endblock** (actual test run)

Nuclotron-type Dipole – Loss Mechanisms

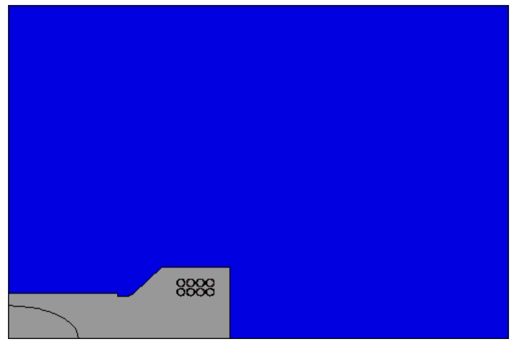
Measured Heat Releases to Helium (4K) Triangular cycle: 1Hz, 0-2T	Nuclotron-Dipole (1.4 m)	80KDP2 (1.4 m) (Yoke at 80K)	planned prototype (2.6 m) (based on present R&D status)
Total (W/m)	44	11	17
Yoke (W/m)	> 27	0	9
Coil (W/m)	12	9	6
Static Heat Release (W/m)	5	2	2

SIS 100 Dipole - Alternatives

Nuclotron Superferric Window-frame Dipole
(cold bore, cryogenic pumping)



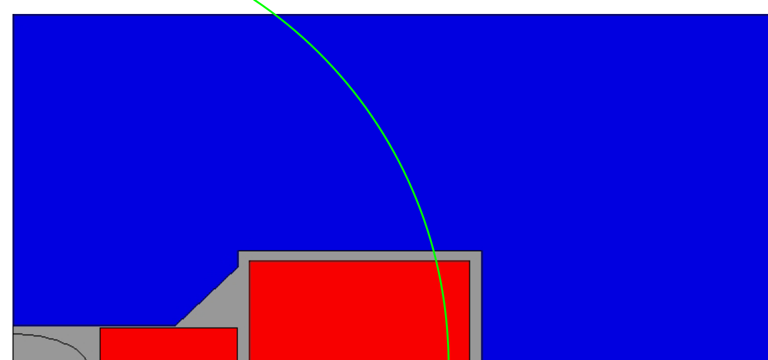
Superferric H-type design
(warm iron, warm bore)



Study at BINP, Russia

Requirements for SIS 100:	
Max. Field:	2 T
Max. Ramp Rate:	4 T/s
Field quality:	$\pm 6\text{x}10^{-4}$
Aperture:	$110\text{x}55\text{mm}^2$

Resistive



Comparison sc and nc 100 Tm dipole

COSTS (M€)	sc	nc
PRODUCTION	36	37
OPERATING	8	45
TOTAL	44	82

based on:

•248 dipoles (SIS 100 and beamlines)

•20 years of operation, 6500h/ y

•present status of the R&D

•present aperture (55 x 110)

•operation cycles mix

•present electricity costs

includes costs for

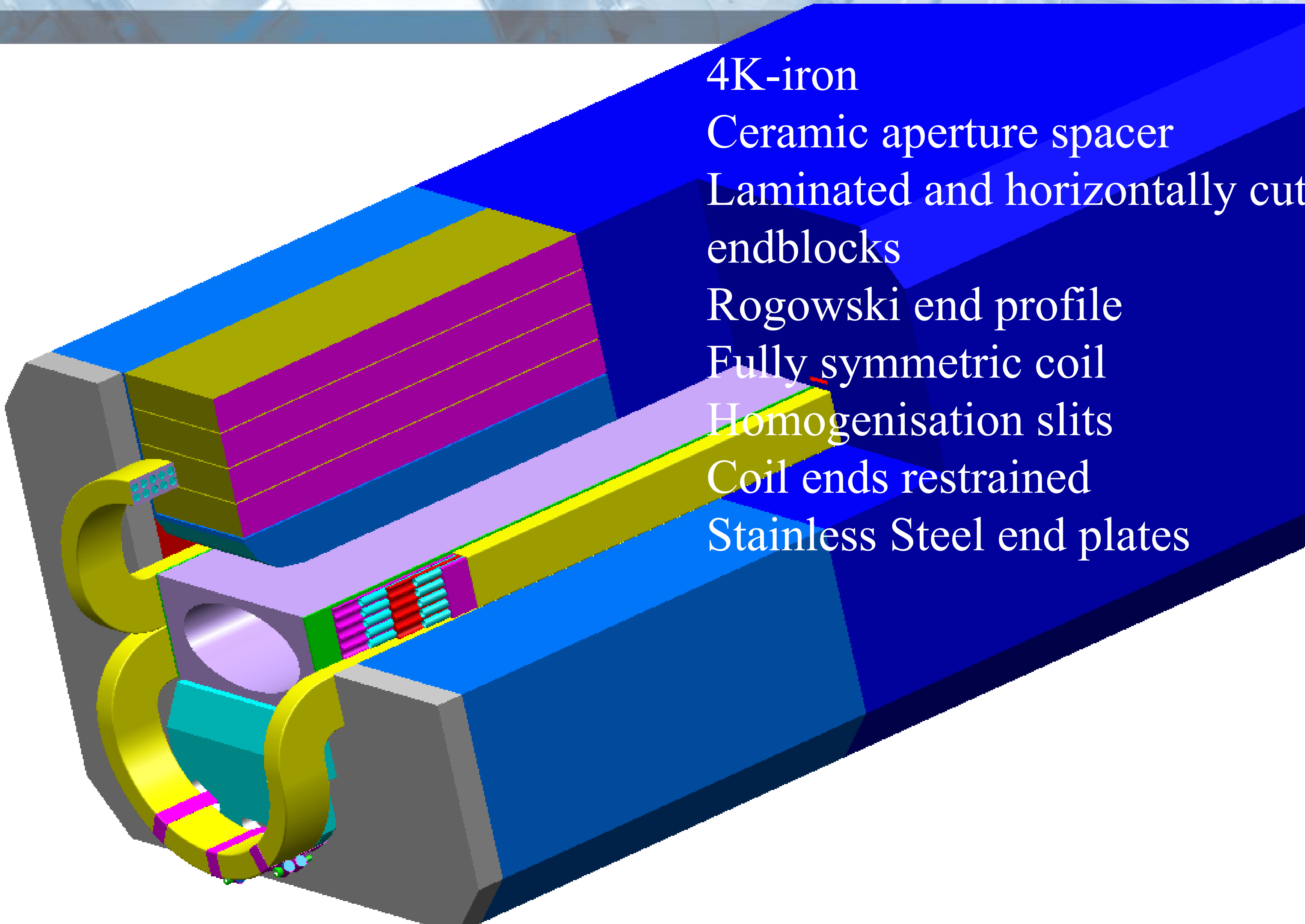
•power supplies, quench detection and protection

•cryogenic system

•tests and operation crew

→**saves 17 000 t CO2 / year**

Vision of the final magnet (4K)



4K-iron

Ceramic aperture spacer

Laminated and horizontally cut endblocks

Rogowski end profile

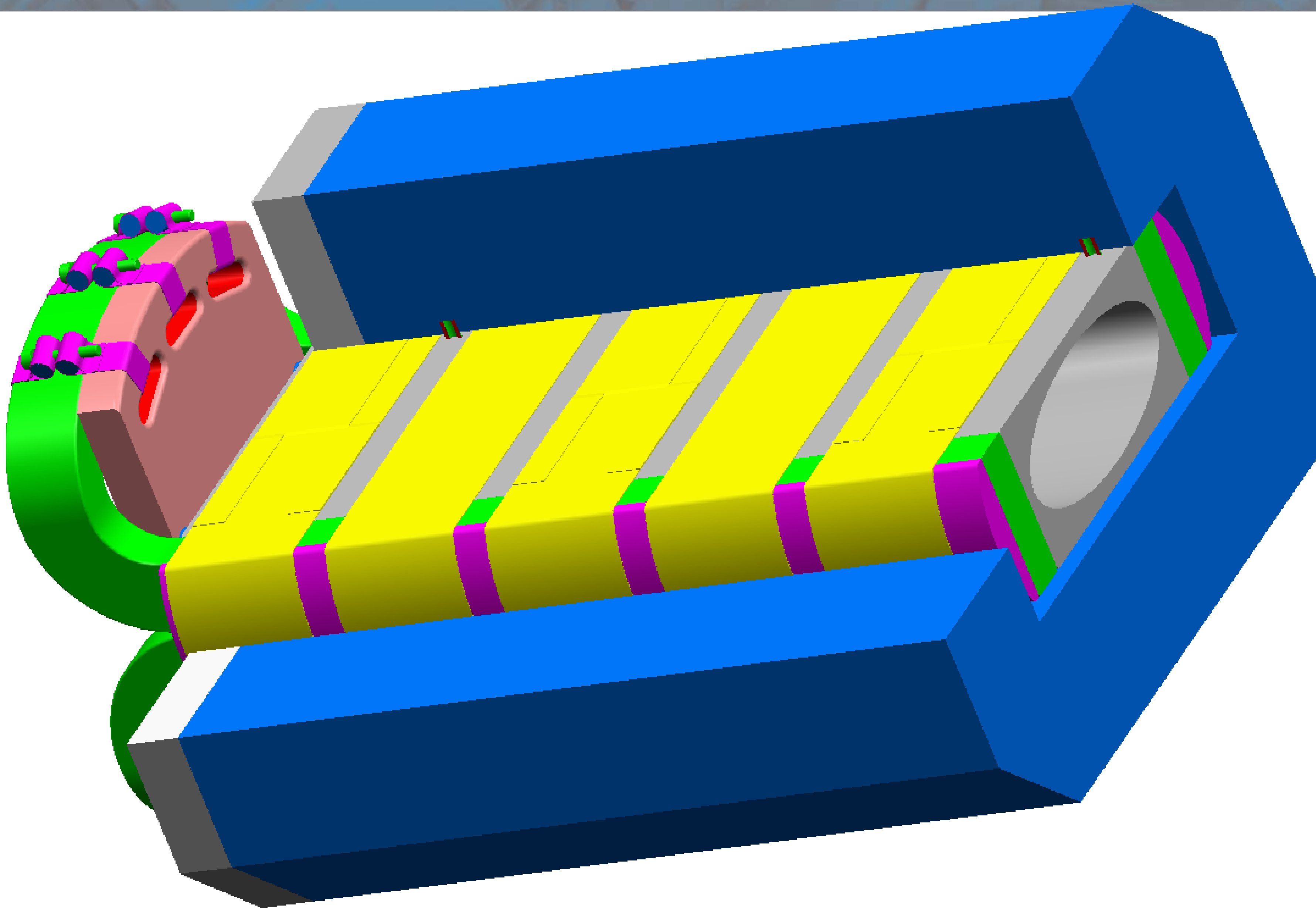
Fully symmetric coil

Homogenisation slits

Coil ends restrained

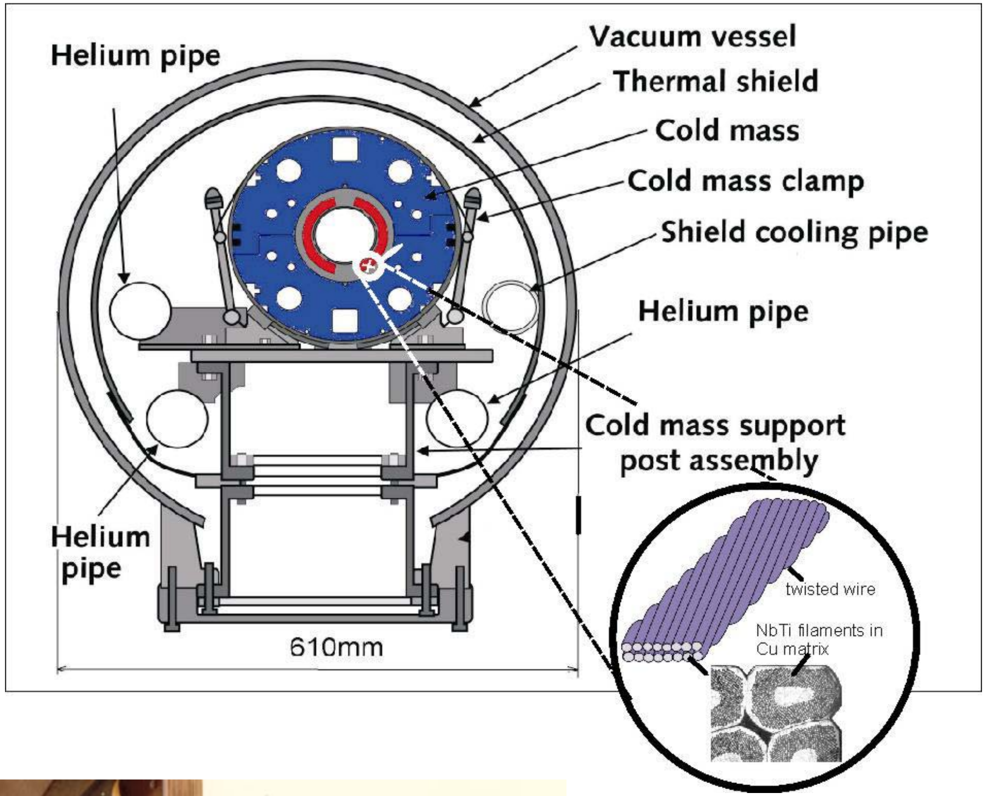
Stainless Steel end plates

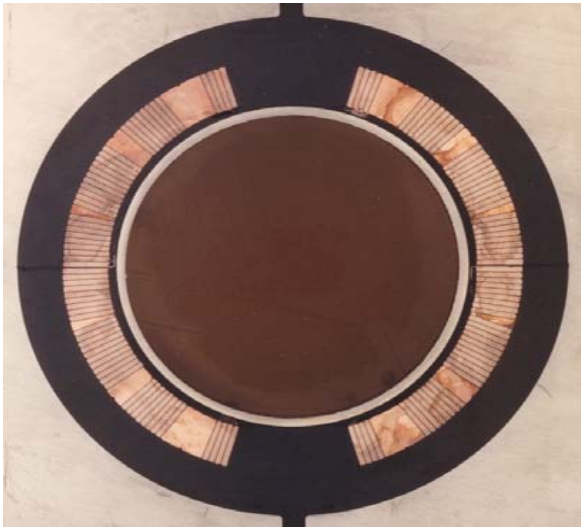
Vision of the final magnet (iron at 80K)

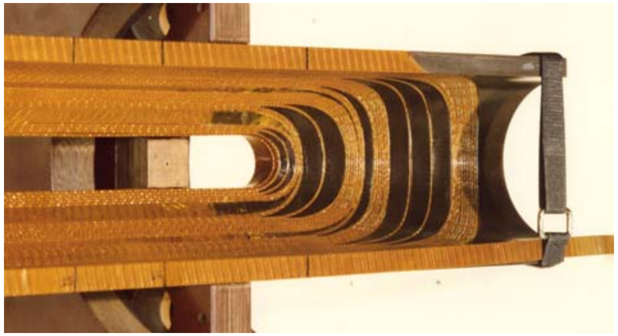


Superconducting Accelerator Magnets: SIS 300

- RHIC dipole
- Collaboration with BNL
- Coil dominated: cosθ
- Maximum field: 3.5 T ⇒ 4 T
- Ramp rate: 70 mT/s ⇒ 1 T/s !!!
- Supercond. Rutherford cable
- One-phase helium cooling

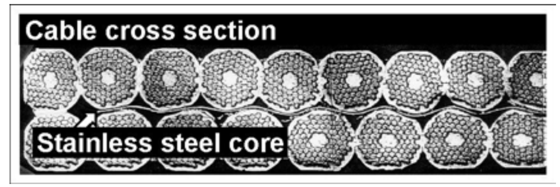


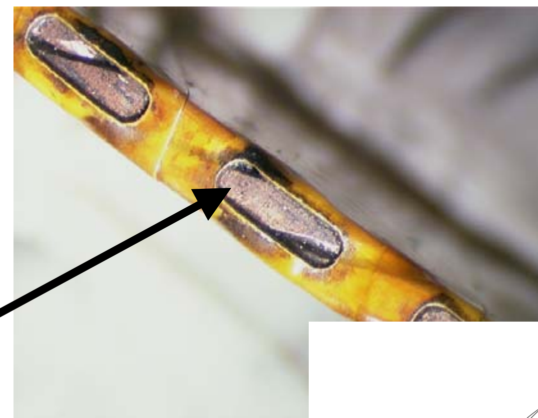


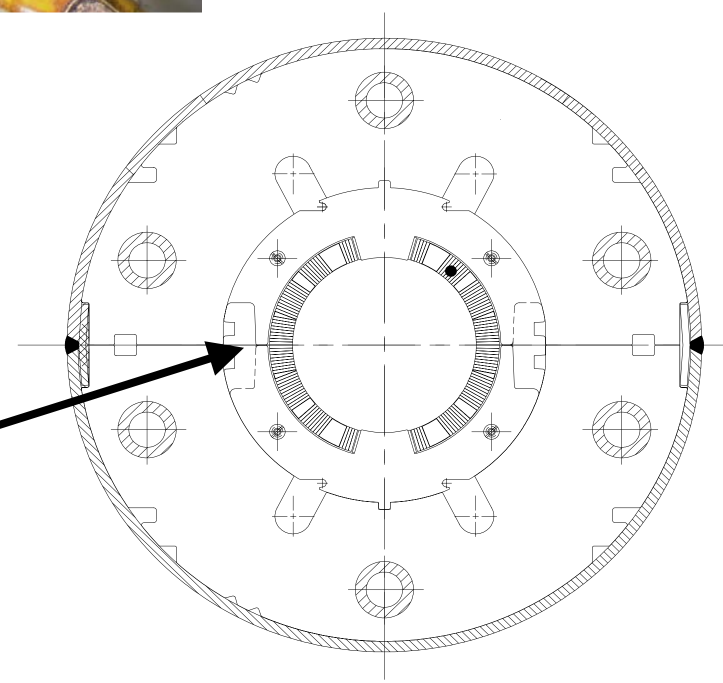


R&D Goals for RHIC type dipole

- Reduce the effects due to the high ramp rate:
  - lower loss in wire, cable (core) and iron
  - better AC field quality
- Improve the cooling of the Rutherford cable
  - open Kapton insulation with laser cut holes
- Use collars to ensure long-term mechanical stability







collar

Dipole Parameters

RHIC dipole

Superconducting wire:
- NbTi-Cu (1:2.25)
- filament diameter 6 μm
- twist pitch 13 mm
- no coating

Rutherford cable
- no core

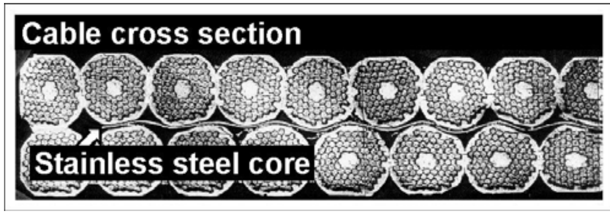
Coil
- phenolic spacer
- Cu wedges

Yoke
- Hc= 145 A/m
- 6.35 mm laminations

RHIC type dipole GSI 001

Superconducting wire:
- NbTi-Cu (1:2.25)
- filament diameter 6 μm
- twist pitch 4 mm
- Stabrite coating

Rutherford cable
- 2 x 25µm stain-less steel core



Coil
- stainless steel collar (G11 keys)
- G11 wedges

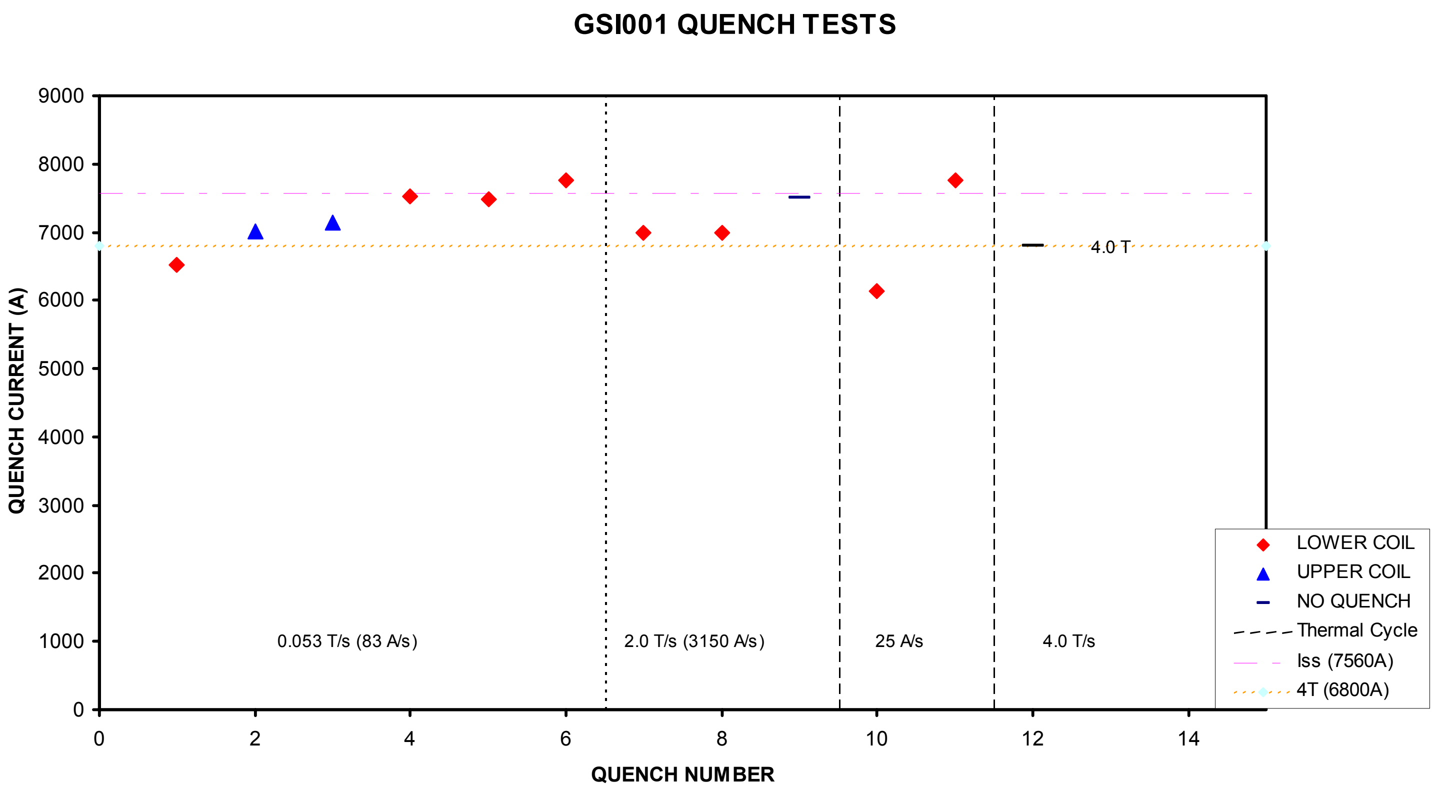
Yoke
- Hc= 33 A/m, 3.5% Silicon
- 0.5 mm laminations, glued

RAMP RATE TESTS

Ramp to 4T without quenching:

4T/s – 3 cycles – 2X

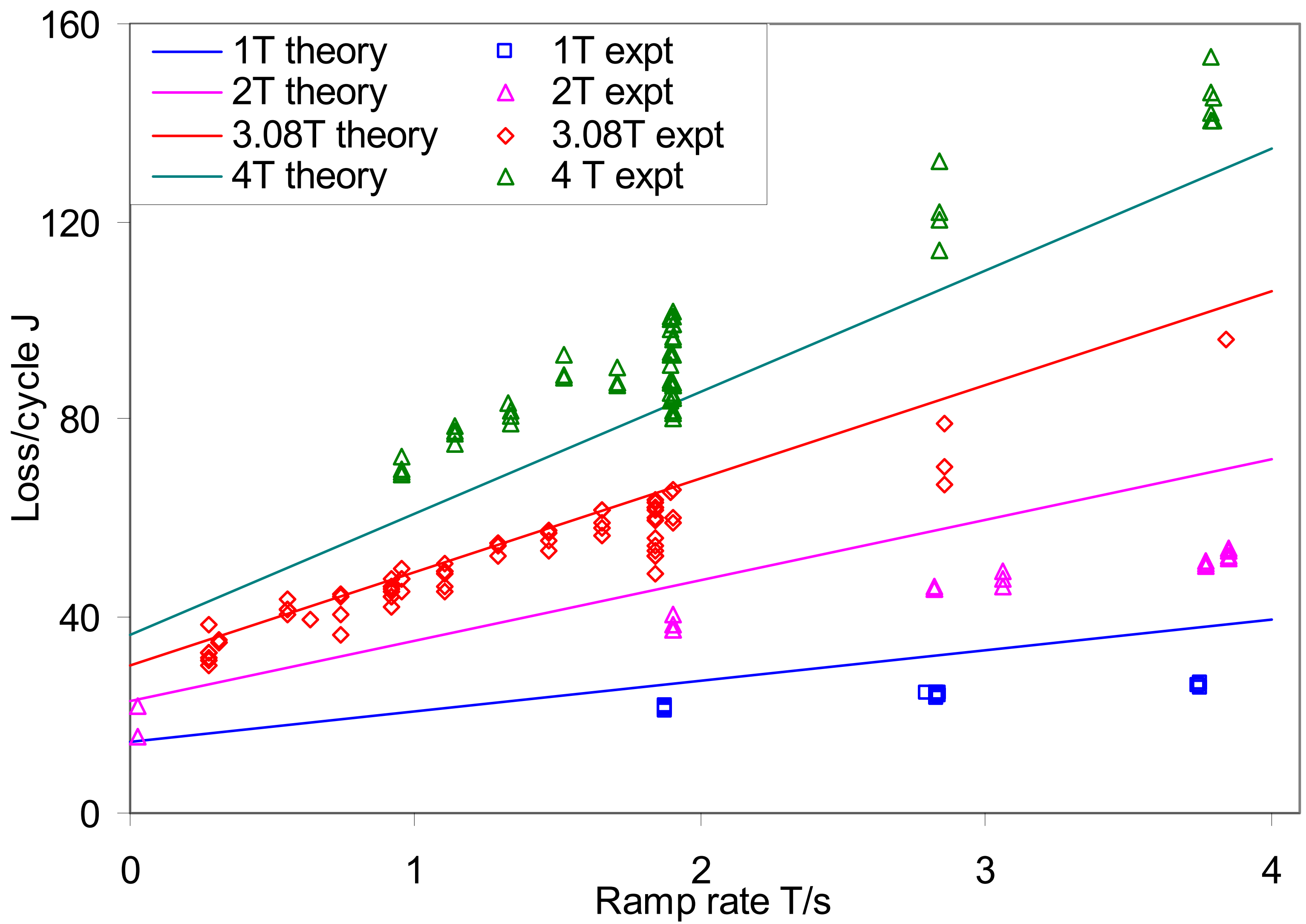
2 T/s – 500 cycles – 40 minutes



Thermal time constant ~ 1 min.

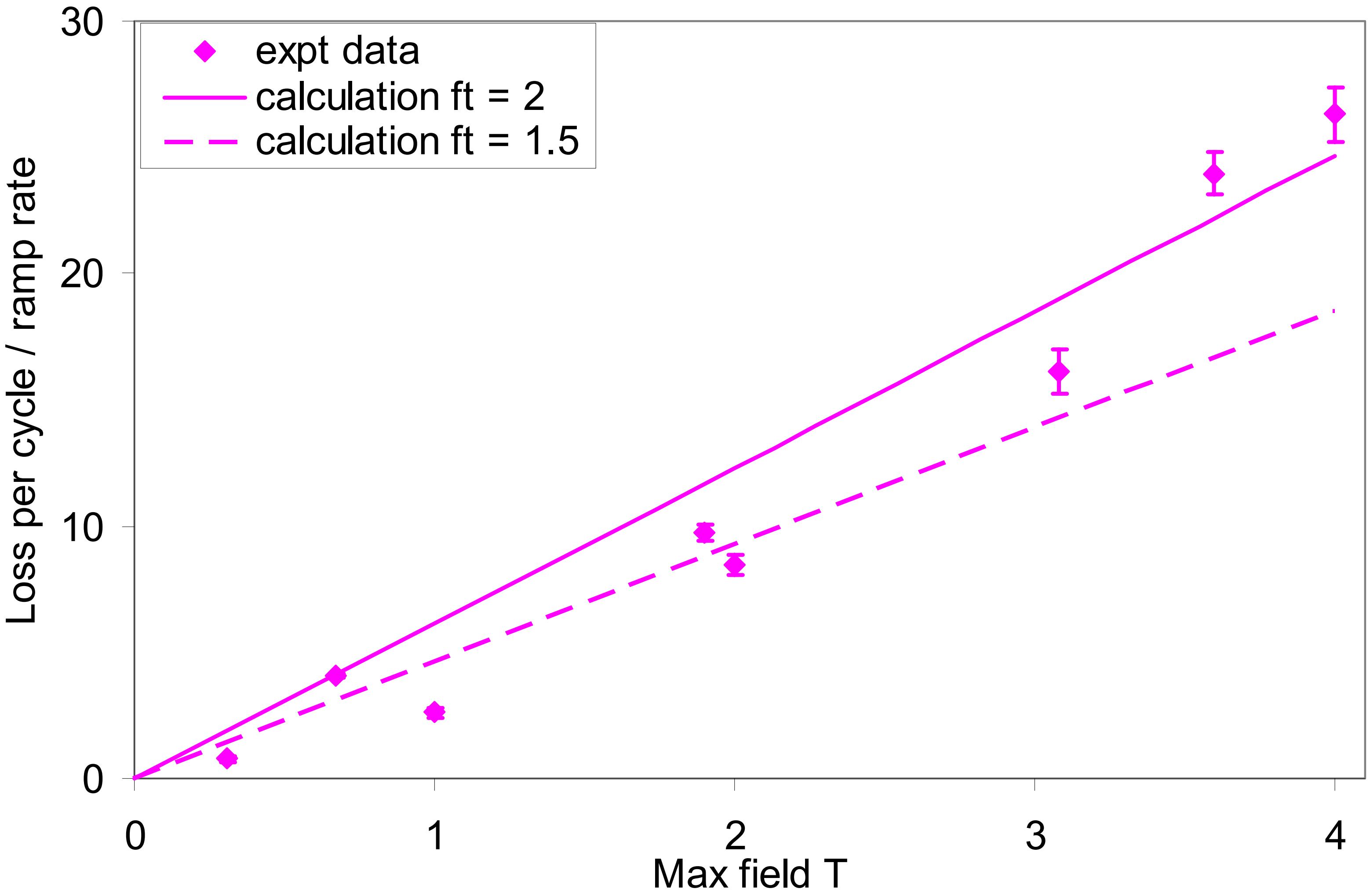
by P. Wanderer

Calculated and measured losses for GSI 001



by M.N. Wilson

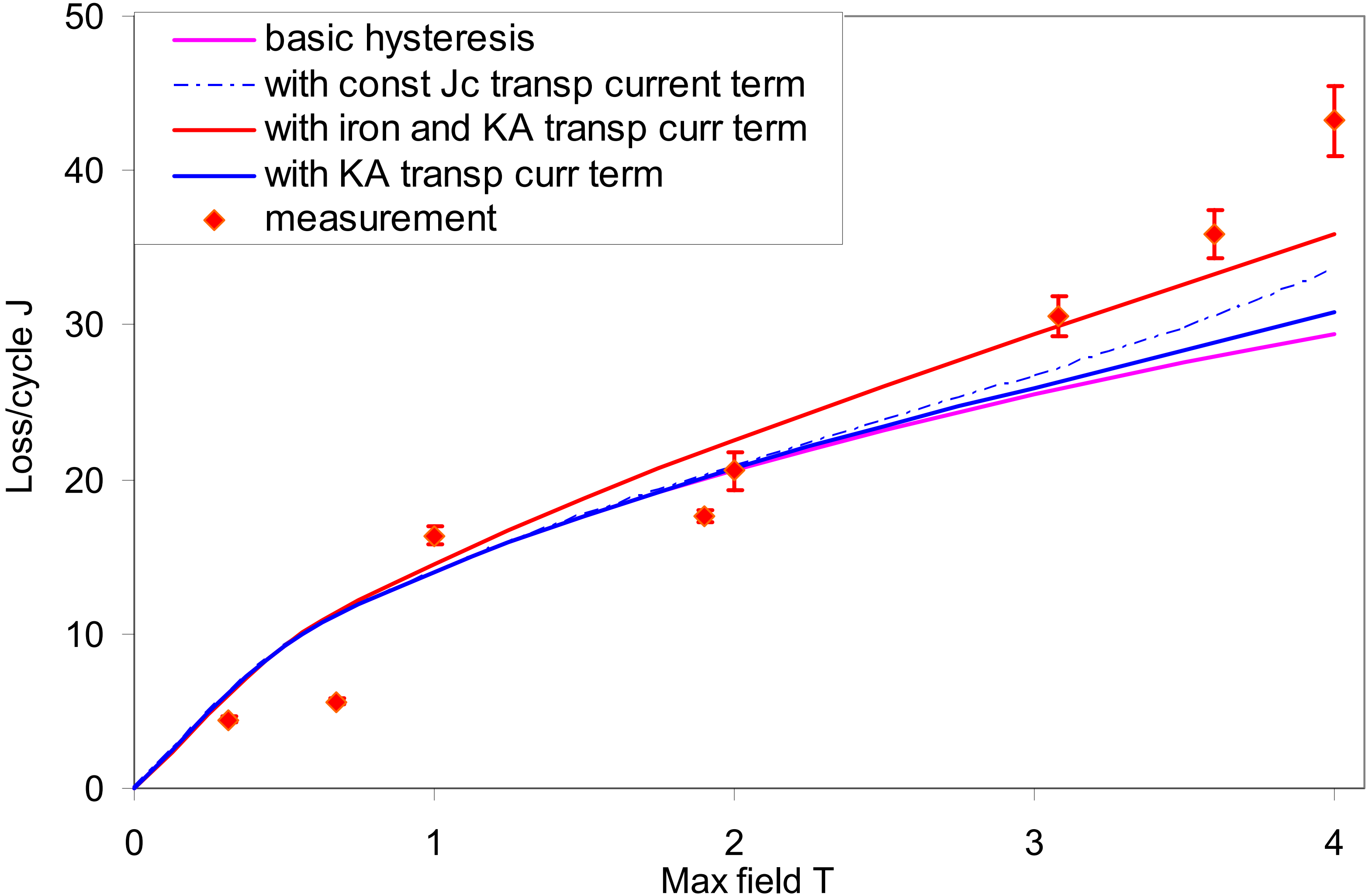
Calculated and measured gradients (rate dependent or eddy current terms)



by M.N. Wilson

Calculated and measured intercepts (hysteresis term)

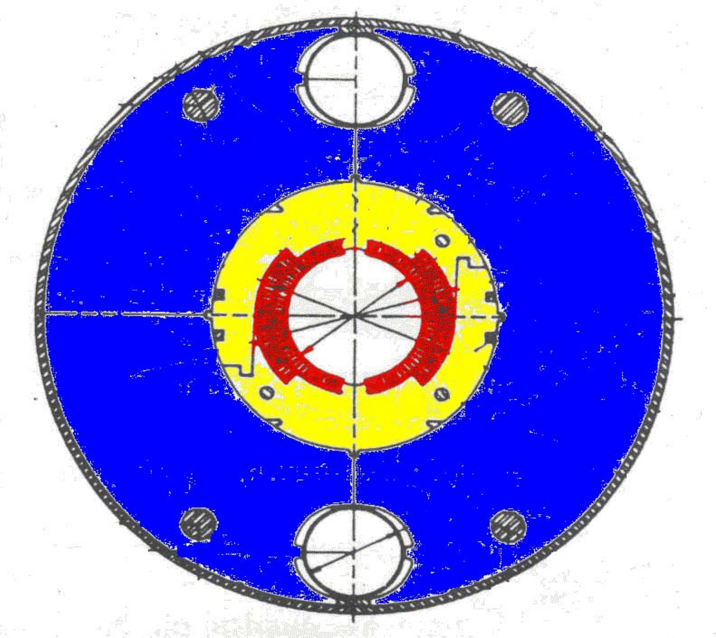
by M.N. Wilson



the theory works pretty well!

good enough to design magnet cooling and refrigeration for the final project

SIS 300 - Dipole Parameters



Goal: 6T, 1T/s

Study by Technopark Kurchatov (Kurchatov Institut Moscow, IHEP, Protvino): Such a magnet is feasible, but needs a lot of R&D !

UNK Dipole

- 2 layer cosθ design
- 80mm bore $\Rightarrow$ 100 mm
- 5.11 T
- 0.11 T/s

SuperFRS, CR, NESR - Magnets

- Low to moderate field/gradient
- DC operation or slowly pulsed
- Large apertures

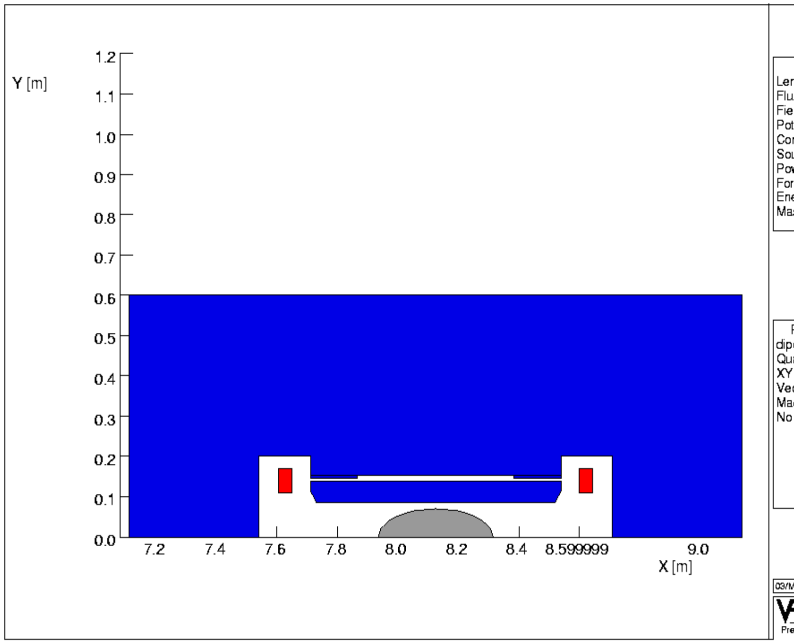
$\rightarrow$ good candidates for superferric magnets

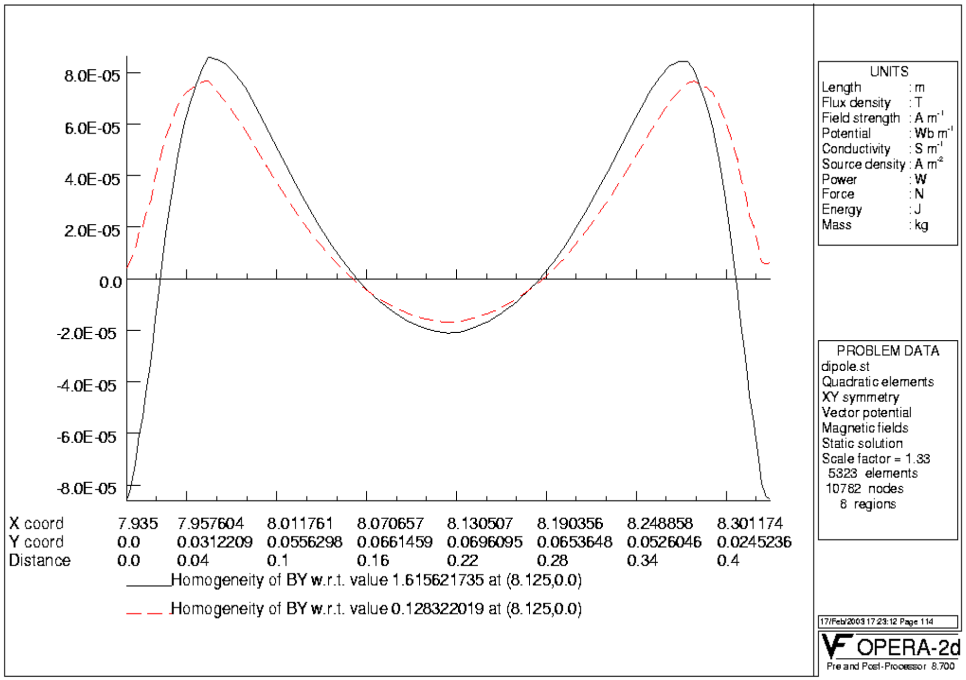
Feasibility-study by MSU (A1900 separator) investigated the different options.

Main challenges: large size of the magnets

high radiation level (Super-FRS)

Cross section of the sector dipole magnet.





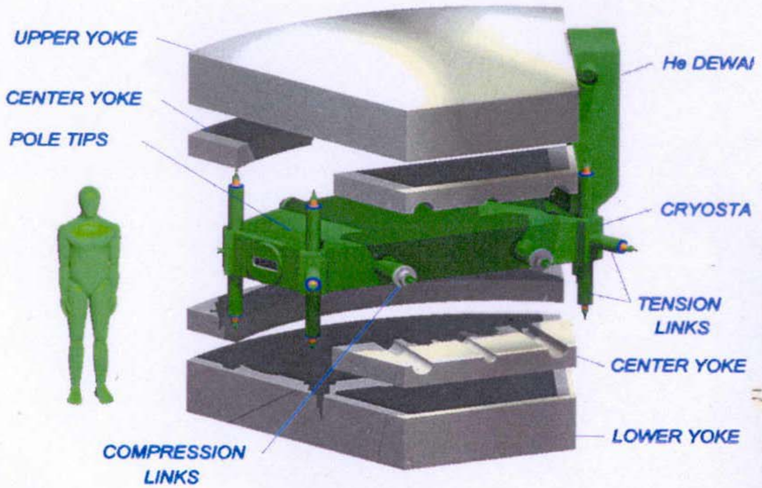
H-type with air filter, curved coil !

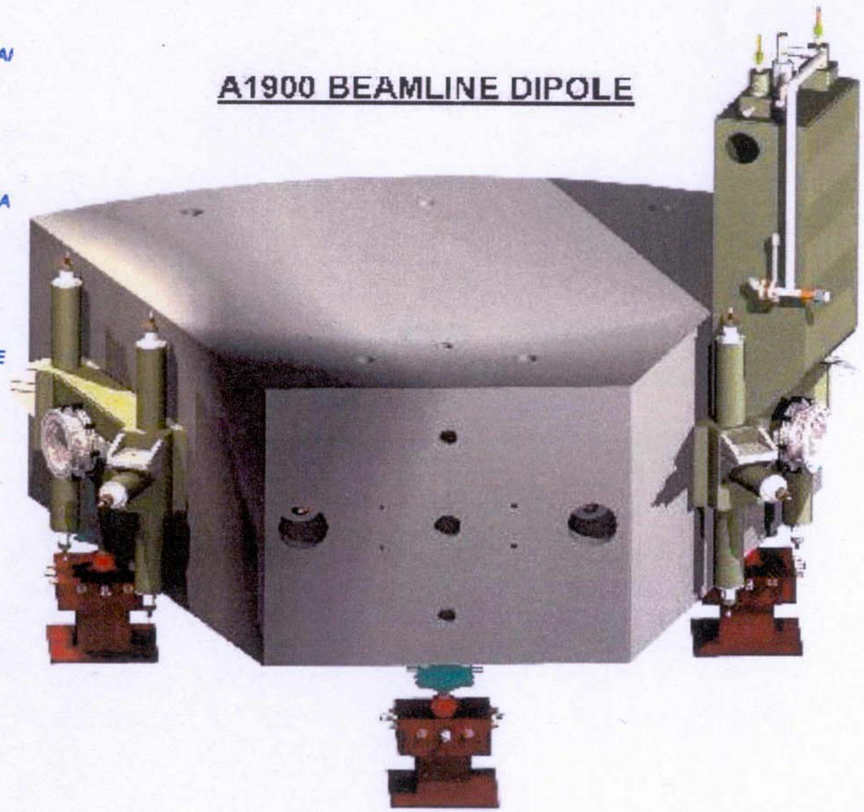
Magnetic field on the border of elliptical aperture for the sector magnet with air filter.

B = 0.13 T (red), B = 1.62 T (black).

A 1900 Dipole

A1900 Dipole



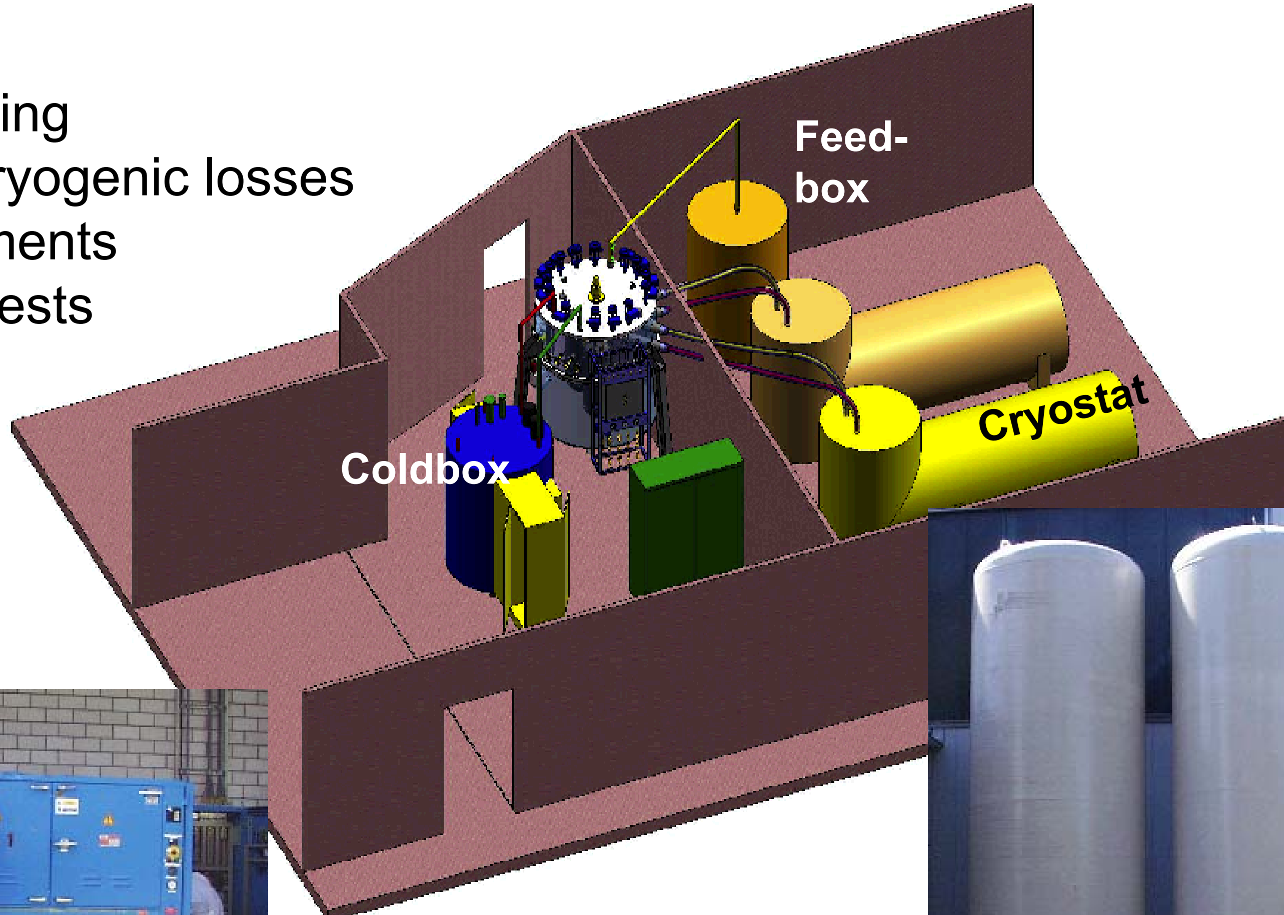


45 degrees bend

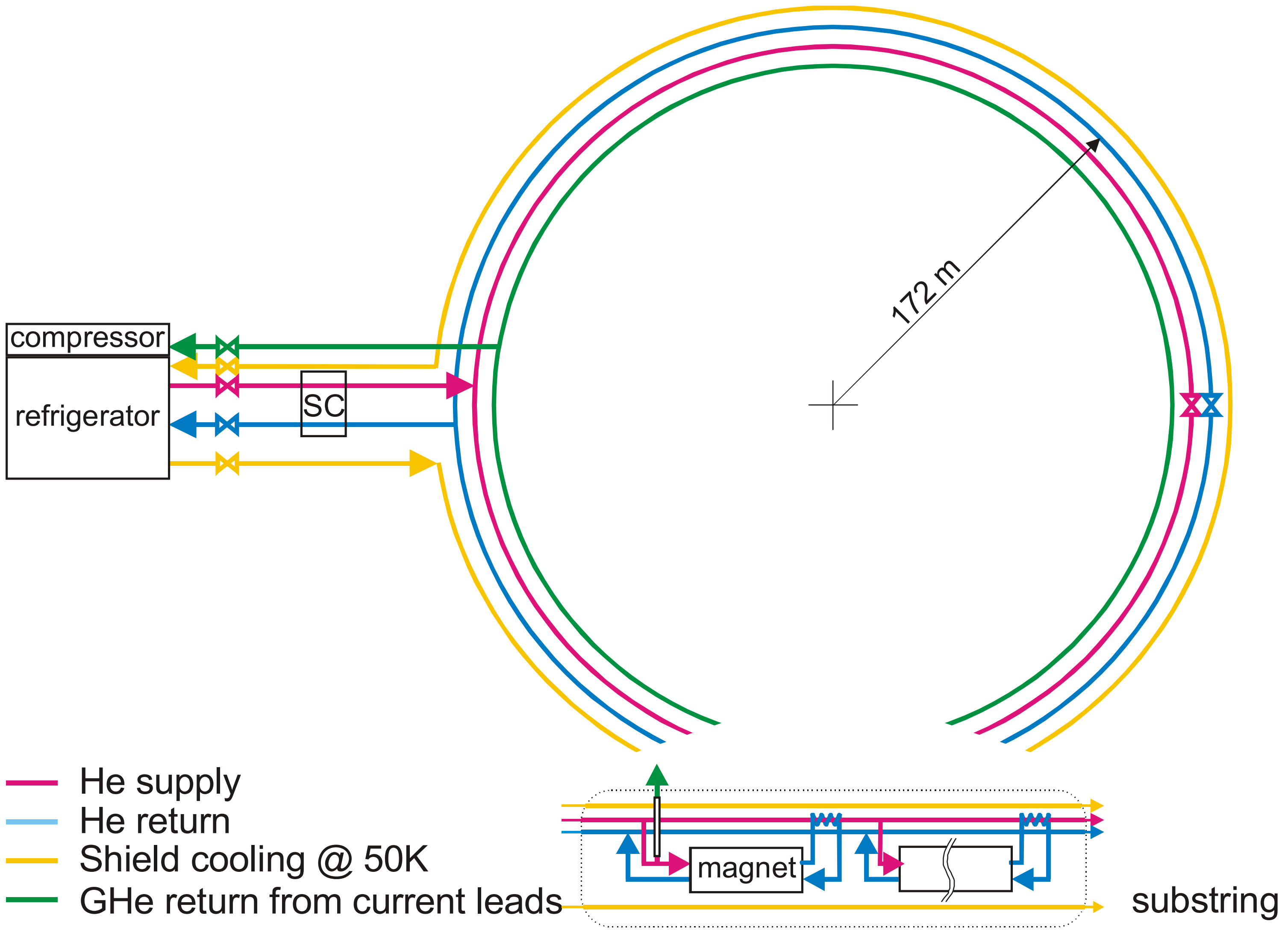
$B_{max} = 2$ T

Planned Magnet Tests on model and prototype magnets

- Quenches and training
- Measurements of cryogenic losses
- Magnetic measurements
- Long term stability tests



SIS 100 – Distribution System



Alignment and Fiducialization of Superconducting Magnets

Simultaneous, combined magnetic / geometric measurements needed !

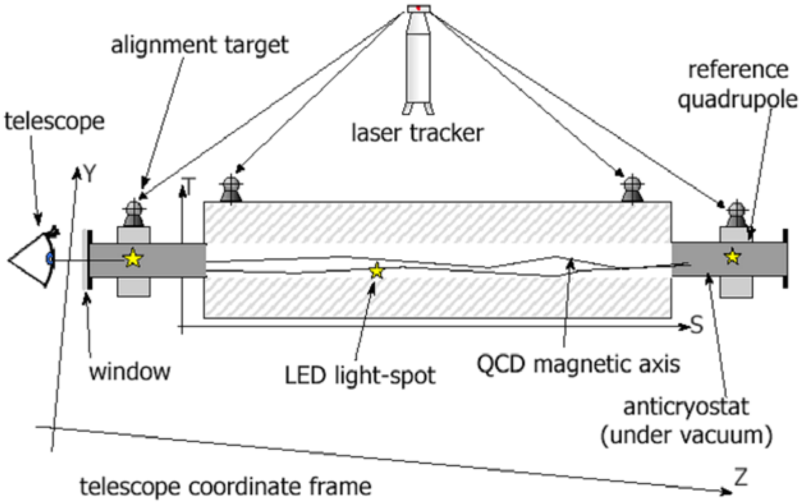


Fig. 5. Overall scheme of the magnetic axis fiducialisation procedure, carried out with a high-field mole at cryogenic temperature.

[LHC Project Report 553]

Additional information required:

- Dimensional quality control of magnets (manufacturing tolerances)
- Movement of magnet vs. cryostat (warm/cold, quench, transport)
- Stability of cryostat under different conditions ($\rightarrow$ stability of fiducials)

Summary

•Fast Cycling Superconducting magnets are an important part of the IAF.

We made very good progress , but need more R&D !

Thanks to all members of the collaborations and the magnet group.!